Solid-State Drives in Embedded Systems

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Key concepts:

- Improvements in technology have made NAND-based solid-state flash drives increasingly attractive to the embedded sector
- Benefits of flash drives include convenience, durability, availability and other factors, but there are still potential disadvantages
- By understanding the application, the user can select the correct flash drive for the job and mitigate any potential pitfalls

Introduction

Typical rotating media is perceived to be among the most significant causes of machine downtime in industrial applications. The ubiquity of relatively inexpensive NAND-based flash memory has led to the development of large storage media that has no moving parts. Due to this, the arrival of NAND flash-based solid-state drives (SSDs) has been met with great anticipation in the embedded sector. The promise of permanent storage devices that are not susceptible to the rigors of harsh embedded environments is too attractive to be ignored.

Unfortunately, simply applying this technology to an embedded application is not without its pitfalls. There are issues that must be considered before including a flash SSD in an embedded application.

The Advantages of Flash SSDs

Availability – Flash devices are everywhere. From smartphones to USB drives to children's books and toys, flash is in almost every product that has a power source. Portable flash drives have single-handedly replaced the aging floppy drive and reduce the need for CDs and DVDs. This abundance has driven prices down and densities up to the point that flash-based hard drives are a reality.

Convenience – Flash-based SSDs have become sufficiently mature enough to act as drop-in replacements for their magnetic counterparts. The 2.5" form factor has become the de facto standard in the industry. Many laptops and netbooks are available with flash drives as their only storage mechanism.

Durability – This is the attribute that makes flash SSDs so attractive to the embedded marketplace. Flash drives have no moving parts, so there are no bearings to wear out or read heads to crash onto the surface of the media. They can be subjected to vibration that is an order of magnitude higher than the best hard drives can manage. Some in the storage industry have indicated that flash drives have a 20-times durability advantage over their rotating counterparts.

Temperature – Due to the lower power consumption of the standard flash SSD, these units typically generate much less heat for a device or enclosure to dissipate. In the industrial world of fanless PCs and sealed boxes, this is a significant advantage.

Performance – Most flash SSDs are capable of significantly outperforming magnetic hard drives in two important areas – read speed and latency. Even though typical write performance is only on par with hard drive capabilities, this performance advantage is tangible when using a PC equipped with a standard operating system.

Noise – Flash drives are completely and eerily silent. When combined with a fanless IPC, the solution creates no noise pollution at all.

A Fly in the Ointment

There are a few disadvantages to using flash SSDs:

Cost – It is unlikely that flash prices will ever catch up with the amazingly low cost per gigabyte of rotating media. Even in the most expensive enterprise form factors, magnetic media is many times less expensive than flash.

Write Speed – Due to the way that flash media is managed, and more specifically, the way it is erased, write speed can be significantly slower than the write speed of magnetic media. This is especially true for the more frequent small size **random** writes to the drive that a general purpose operating system is likely to do. Random writes to a well-used drive can force a condition known as write amplification. This condition creates read/erase/write cycles in order to write a small amount of data. This can slow write speeds down to a crawl.

Endurance – Here we introduce a new term to the world of storage media that is a distinction from the concept of durability. Flash SSDs have better *durability* than magnetic media, but they have worse *endurance*. Flash media is limited in the number of times it can be erased. Worse news is that because of the way operating systems handle their storage, writing to areas around the same location can force several erase cycles to the same flash memory.

Solutions

The benefits of using flash drives in embedded applications outweigh the disadvantages. In addition, there are several ways that a user can mitigate the problems associated with these drives. It is important to understand the applications that are deployed on flash drives and properly match the right drive with the installation.

SLC vs. MLC – The same NAND flash cells can be treated as single-level cells (SLC = one bit stored per cell) or multiple-level cells (MLC = multiple bits stored per cell). When flash memory is rated and used as MLC, the technology requires higher voltages and multiple cycles to access all of the data stored in a cell. This usage pattern makes MLC drives much slower, and they have less endurance than SLC. The offset is that because of the higher densities of MLC flash, it is much less expensive than SLC flash. So MLC memory is much more common in flash drives, especially as the storage size of the device gets larger. Drive manufacturers have invested significantly into controllers for MLC-based flash drives that can reduce the performance and endurance limitations. Even so, most enterprise class flash drives use SLC memory due to the endurance and performance requirements.

Usage Models – Even the best flash drives can have their write cycles quickly used up by heavily write-oriented applications. In the majority of embedded installations, flash drives will provide an advantage over magnetic media. When used with a general purpose operating system, a flash drive will boot faster and respond quicker when the application is dealing with static data. When used with an embedded operating system that uses a RAM-based file system, flash drives are a perfect match and will likely outlast the other components in the system. When used with a heavily write-oriented application like a transaction-oriented database server, however, the wrong type of flash drive can be quickly used up.

Advanced Algorithms – To increase the endurance of flash drives, manufacturers have designed controllers that manage erase cycles better. This maximizes the number of erase cycles that the drive can tolerate. Additionally, these controllers distribute the data across the entire drive to ensure that the flash media wears evenly. Some of these drives are even capable of moving static data around without affecting overall system performance.

Additional RAM buffers – All flash drive controllers use some amount of integrated memory for their own purposes, but some drives add significant external RAM for buffering purposes. The use of RAM buffering can increase the performance of a flash drive, but more importantly, can significantly increase the endurance of the drive. The controller can use this buffer to delay writing and combine multiple writes into the same block, reducing the amount of erasing that occurs on the drive. These RAM buffers are frequently used to cache the internal relocation information used in the wear leveling algorithms, further reducing the write cycles to the flash.

The TRIM Command – Operating systems were not originally designed to optimize the use of flash drives. One of the most significant problems is that the block storage device is not notified when storage blocks are no longer in

use. When a file is deleted, for instance, the file system just internally marks the blocks as no longer in use and overwrites them when convenient. The problem with this usage model is that a flash drive will continually preserve this unnecessary data, amplifying the number of erase cycles that are necessary for a given block. The TRIM command was added to drives to mitigate this problem. Starting with Windows 7, the Windows operating system now uses the TRIM command to notify a flash drive when blocks are no longer in use. Some drive manufacturers have released tools and drivers that allow the use of the TRIM command on earlier version of Windows.

Enterprise-class flash drives – MLC flash is typically rated for 10,000 program/erase cycles per block, and SLC flash is typically rated for 100,000 program/erase cycles per block. When an application calls for extreme write endurance, there are drives that incorporate flash that can sustain as high as 1,000,000 program/erase cycles. These drives fall into the high end of enterprise-class drives and are priced to match.

Monitoring Tools – Many manufacturers provide interfaces or tools that allow the user to monitor the state and health of their storage devices. Leveraging on the Self-Monitoring, Analysis, and Reporting Technology (SMART) interface of device monitoring designed for magnetic media, these tools can be an integral part of evaluating the suitability of a device to a specific application.

Application Guide

When deploying flash drives into an embedded environment, it is important to understand how the drive will be used. Periodically checking the state and health of these drives once deployed is also extremely important.

Application	Suggestion
Embedded application with minimal drive access	An inexpensive MLC flash drive will keep the overall system cost down and deliver good performance with sufficient lifetime.
Embedded application with intermediate drive activity. Daily program/erase of <20 GB/day	Using an MLC flash drive with an advanced controller and supplemental RAM will provide good value and better endurance than a less expensive drive. Installations that are using standard operating systems with a swap file should use at least this type of drive.
Embedded application with heavy drive activity, such as a data logger or intermediate database application. Daily program/erase of <100 GB/day	Switching to a drive that uses SLC NAND flash will allow for the increased program/erase cycles of this application. The cost goes up substantially.
Embedded application with extreme drive activity, such as a transactional database server. Daily program/erase of <1 TB/day	A flash drive that combines an advanced controller and high-endurance SLC NAND flash can handle this type of application. It is also possible to use a flash drive with MLC that has an enterprise-class controller with significant RAM and superior erasing algorithms.

Summary

Flash drives built on NAND flash technology have improved in performance and capability and are very attractive devices for use in embedded solutions. A wide range of drives are available, and to maximize this potential, it is important to understand that all solid-state drives are not created equal. The user must take care in selecting a device that is appropriate for the application.

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